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Research and Analysis of Solar Heating Biogas Fermentation System

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Abstract

Firstly this paper designs solar heating biogas fermentation system, its volume is $6m^3$, and than calculates digester's heat load based on Hohhot's weather data. Finally, a U-tube collector system was carried out for 5 month experiment, this paper use October's experimental data, looking for the heat matching relationship between the solar collector system and biogas fermentation system. We can conclude that at Hohhot, in October, the heat was absorbed by $2m^2$ solar collectors that was ran 8 hours can met the $6m^3$ digester 's fermentation heat demands.

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*Keywords:*Biogas; solar; heat; design; experiment;

1.Introduction

Hohhot is the home of dairy, according to statistics, there are 5.4×10^6t animal feces were produced every year, this is the objective condition of development and application biogas, as in [1]. Development and application biogas is not only can reduce the environment pollution and use animal feces effectively, but also can save the consumption of coal resources, so it can brings environmental, economic, social and many other benefits. As we known, temperature is an important factor in biogas fermentation, a temperature of 35 ± 2℃ has proven most efficient for production of biogas, so it is necessary to use solar heating system to ensure the normal operation of biogas fermentation in Hohhot.

2.Solar Heating Biogas Fermentation System

Solar heating biogas fermentation system is consist of solar collector system, biogas fermentation system, temperature control system, as shown in Fig.1.

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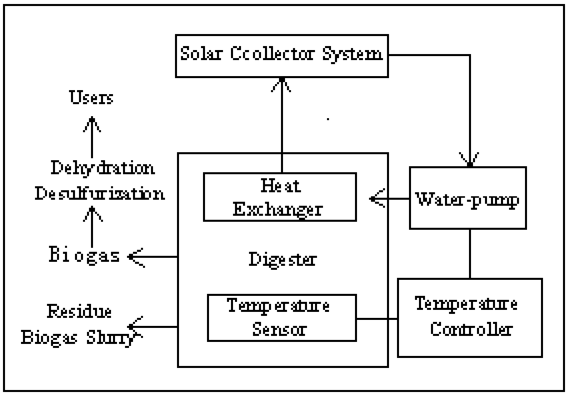


Figure 1. Solar heating biogas fermentation system

3.Design biogas digester

The design requires the temperature maintained among 35 ± 2℃ and sets the gas production capacity is $0.5m^3/m^3d$, as in [2], the biogas is produced can be enough for ten people to use, the biogas consumption of rural households is calculated as $0.3m^3/d$. So the digester volume can be determined by the following formula for the $6m^3$.

$$V = \frac{V_1}{\alpha} \tag{1}$$

Where, V represents the volume of biogas digester; V_1 is required biogas volume; α is the rate of gas production.

This paper uses the cylindrical digester, according to the GB4750, the cylindrical digester is consist of two chopping body and one cylinder between them, the span ratio of the pool cover is $f_1/D=1/5$ and the bottom is $f_2/D=1/8$, than according to the minimum heat transfer area to determine the size of each part of digester, shown in Fig.2.

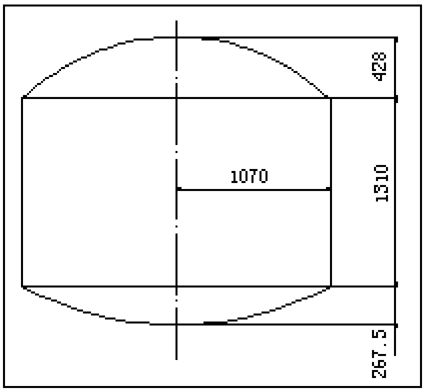


Figure 2. Structural diagram of digester

The digester is optimized through the above process, not only can get the optimal size to meet the minimum heat transfer area, but also meet the design principle of “around, small and shallow", at the same time, digester’s total cost can make minimize, as in [3].

4.Heat balance of biogas fermentation system

After analyze this system using thermodynamics we can know that this is an open system in which the input is biomass and solar, the output is residue, biogas, biogas slurry and the heat to the environment, therefore, the system's heat balance equation is:

$$Q = Q_b + Q_s + Q_w + Q_z \tag{2}$$

Where, Q represents the heat load, Q_b is the heat of reaction, Q_s is the heat of dissipation to the surrounding environment, Q_w is the heat of the manure, Q_z is the heat of the effluent.

The heat of the effluent is very small, so it can be ignored. In addition, many researchers believed that the fermentation process activity is not strong,, so the heat produced by biological fermentation has little effect on the system's temperature, and no exact value, so the reaction heat can be ignored. Therefore, the heat balance equation can be simplified as:

$$Q = Q_s + Q_w \tag{3}$$

4.1.The heat of dissipation to the environment

The heat of dissipation to the environment is consist of the heat losses from the top, the sides and the bottom of digester:

$$Q_{s1} = a_1 q_1 \;.\; a_1 \frac{t_2 - t'}{\frac{1}{h_1} + \frac{\delta_1}{\lambda_1} + \frac{\delta_2}{\lambda_2} + \frac{1}{h_2}} \tag{4}$$

$$Q_{s2} = a_2 q_2 \;.\; a_2 \frac{t_2 - t}{\frac{d_3}{d_1 h_1} + \frac{d_3}{2l_1} \times \ln(\frac{d_2}{d_1}) + \frac{d_3}{2l_2} \times \ln(\frac{d_3}{d_2}) + \frac{1}{h_2}} \tag{5}$$

$$.\; Q_{s3} = a_3 q_3 \;.\; a_3 \frac{t_2 - t}{\frac{1}{h_1} + \frac{\delta_1}{\lambda_1} + \frac{\delta_2}{\lambda_2} + \frac{1}{h_2}} \tag{6}$$

Where, δ and δ_2 are the thickness of digester wall and insulation respectively, λ_1 and λ_2 are the thermal conductivity of digester and insulation materials respectively, h_1 and h_2 are the heat transfer coefficient between manure and the inner wall of digester, soil and the outer wall of digester respectively, t and t' are soil temperature at different depths, a_1 , a_2 and a_3 are the area of the top, the sides and the bottom of digester respectively.

TABLE I. MATERIAL PROPERTIES OF DIGESTER

Material	Thickness(mm)	Thermal Conductivity(W/m● k)
Reinforced concrete	200	1.74
Insulation	100	0.028

The soil temperature of Hohhot is given as following equations, as in [4]:
When depth is 0cm, the equation is:

$$Tsoil = 4.593 + 1.015 \times Tair - 0.016 \times longitude - 0.029 \times latitude \tag{7}$$

When depth is 20cm, the equation is:

$$Tsoil = 13.65 + 0.781 \times Tair - 0.036 \times longitude - 0.134 \times latitude \quad (8)$$

When depth is 40cm, the equation is:

$$Tsoil = 15.73 + 0.739 \times Tair - 0.046 \times longitude - 0.143 \times latitude - 0.001 \times altitude \quad (9)$$

Hohhot is located in longitude 111.68 °E, latitude 40.82 °N and altitude is 1063m, when the ambient temperature is 10.1℃, According to the formula above, we can compute the soil temperature of the surface, underground 20cm and underground 40cm, listed in table 2

TABLE II. THE SOIL TEMPERATURE OF HOTTOT

Depth(cm)	0	20	40
Soil Temperature(℃)	11.87	12.05	11.16

The main body of digester is reinforced concrete structure and put it underground, when compute the heat load of it, the temperature of the top is 11.87℃,the pool's wall and bottom is 11.16℃, by this method reducing the accuracy and increasing the heat dissipation, but increasing the system's safety factor, so it is desirable.

4.2.The heat of the manure

$$Q_w = cm\Delta t = cm(t_2 - t_1) \quad (10)$$

Where, c represents the heat capacity and approximation for water, 4.2kJ/kg℃; t_1 is the temperature of the influent, 15℃; m is the mass of the influent; t_2 is the temperature of fermentation, 35℃

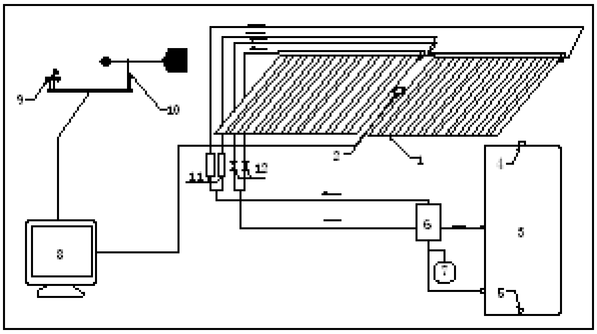
When fermentation temperature is 35℃, fermentation time is 20d, so the digester's daily feed is 0.3 m^3/d, about 300 kilograms，because of setting the fermentation concentration is 10%, the cow dung dry matter content is 17%, and the effective pool capacity is 70%, so we can know the daily dry dung mass is 123kg, at the same tine, it is need to add 177kg water to the digester to ensure the fermentation concentration is 10%.

TABLE III. THE HEAT LOAD OF DIGESTER

Q_w (kJ)	**Q_S (kJ)**			**Q (kJ)**
	Q_{s1}	**Q_{s2}**	**Q_{s3}**	
2.52×10^4	1428	4448	1349	3.24×10^4

5. Experimental results and discussion

5.1.Solar collector system



1 Solar Collector; 2 Radiation Table; 3 Hot Water Tank; 4 Safety Valve;
5 Drain Valve;6 Solar Station;7 Expansion Water Tank; 8 Solar Test System; 9 Anemometer;10 Wind Vane; 11 Flow meter; 12 Valve

Figure 3. U-type tubular collector circulatory system

5.2.Discussion

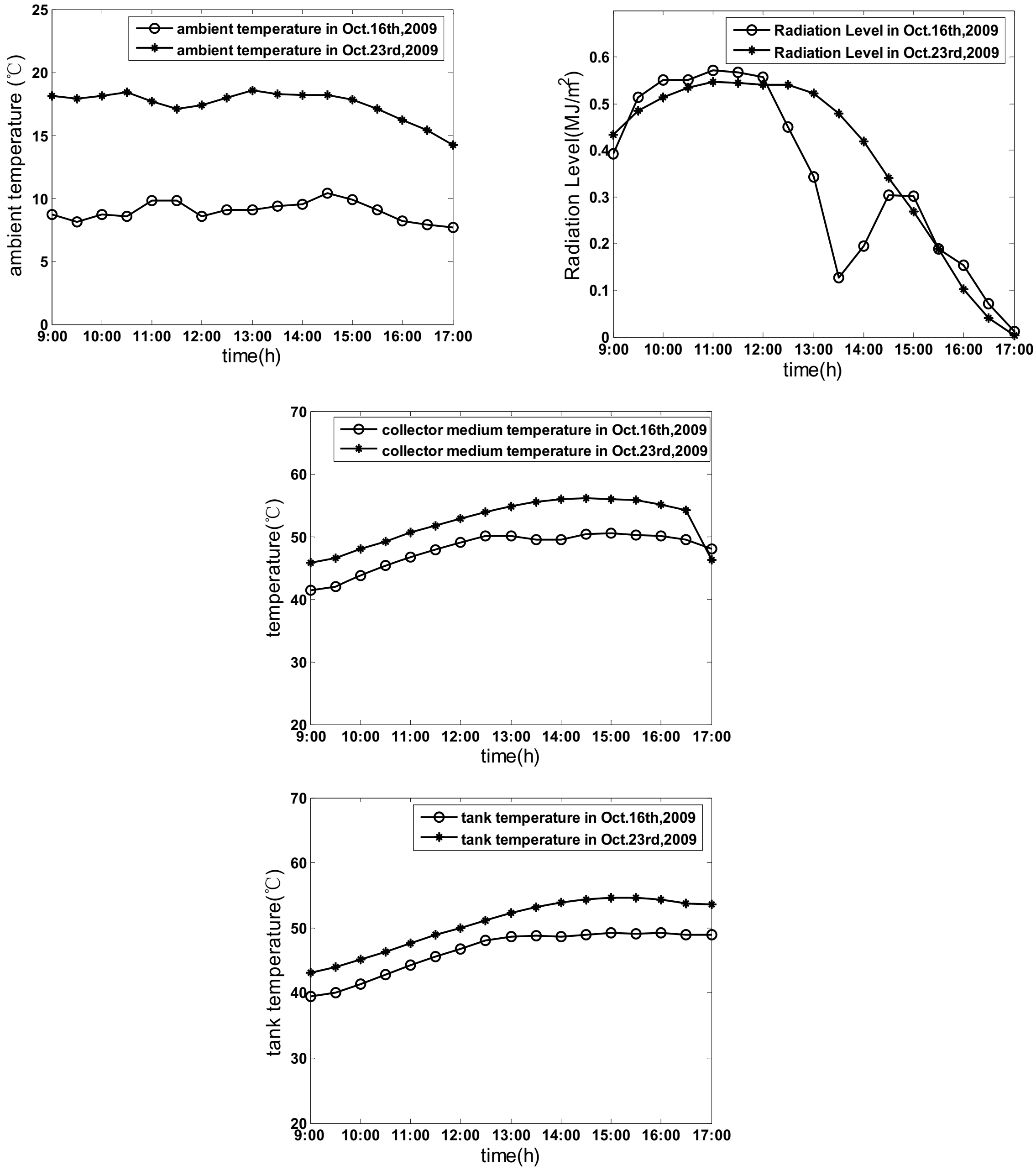


Figure 4. The comparison about ambient temperature, radiation level, tank temperature, solar collector medium temperature

Fig.4 is the comparison about ambient temperature, solar radiation and the medium temperature of collector in two different types of weather condition, it can be seen that the change trend of ambient temperature is the same nearly in October 16 and October 23, but the temperature of October 23 is higher than October 16, because of October 23 was sunny, however, October 16 was cloudy. The solar radiation curve of October 23 is smooth, the solar radiation is gradually increased from 9:00 am to 13:00pm, and then it is gradually decreased until 17:00pm almost zero. While October 16 was cloudy, so the curve is not smooth, but the trend is consistent. October 23 was sunny, so solar collector can absorb more heat, so the medium temperature of collector is higher and it can deliver much heat to the water tank.

5.3.Calculation the storage heat of water tank's

In the experiment, the heat was absorbed through solar collectors was stored in the water tank, the system was ran 8 hours, the water tank's storage heat is determined by the following equation and list the results in table 4.

$$Q_w = q_v \rho c_p T(T_2 - T_1) \quad (11)$$

Where, T represents running time, T_1 initial temperature, T_2 is end temperature, q_v is flow of water tank.

TABLE IV. THE TANK HEAT IN DIFFERENT KINDS OF WEATHER CONDITION

Weather Condition	T_1 (℃)	T_2 (℃)	Flow(m^3/h)	Heat(kJ)
Sunny	45.7	53.8	0.849	3.13×10^5
Cloudy	42.8	49.1	0.899	1.86×10^5

Conclusions

At Hohhot, in October, the heat was absorbed by $2m^2$ solar collectors that was ran 8 hours, some of it for biogas fermentation, and the other part was stored in the water tank. The heat was stored in the water tank could meet digester's demands during 17:00 pm to 9:00 am of next day, it can be shown by calculating, even on cloudy day, the heat was stored in the water tank is 1.86×10^5kJ if the system ran 8 hours, while the heat needed for the biogas fermentation is 3.16×10^4 kJ, so the heat was stored in the water tank can reached 1.54×10^5kJ. Therefore, At Hohhot, in October, the heat was absorbed by $2m^2$ solar collectors that was ran 8 hours can meet the fermentation heat demands of $6m^3$ digester.

Acknowledgment

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